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COMBUSTION OF MIXTURES OF HIGH-CALORIFIC
METAL POWDERS AND WATER

V. V. Gorbunov

Army Foreign Science and Technology Center
Charlottesville, Virginia

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220 SEVENTH STREET NE.
CHARLOTTESVILLE, VIRGINIA 22901

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ABSTRACT:

It was earlier demonstrated by one of the authors that mixtures of magnesium and aluminum with water are capable of explosive transformation. It was concluded that stable detonation propagation in these mixtures is observed only when at least 7% of a sensitizer, pentaerythrityl tetranitrate, is added. Combustion of mixtures of high-calorific metals and water at atmospheric pressure was observed for large charge diameters. Investigation was conducted of combustion of mixtures of magnesium, the alloy Al:Mg=50:50, aluminum with water at increased pressures and the effect of the physio-chemical properties of a metal, aggregate state of water, the Me:H₂O ratio, and other factors affecting degree of oxidation of metal.

Combustibility of mixtures of high-calorific metals and water is determined primarily by ease of oxidation of the metal powder. Degree of oxidation depends on the Me:H₂O ratio in the mixture. Change in the state of aggregation of water does not effect degree of oxidation of a metal.

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It was earlier (1) demonstrated by one of the authors that mixtures of magnesium and aluminum with water are capable of explosive transformation. Medard (2) has concluded that stable detonation propagation in these mixtures is observed only when at least 7% of a sensitizer, pentaerythrityl tetranitrate, is added. Combustion of mixtures of high-calorific metals and water at atmospheric pressure was observed for large charge diameters: 24mm for magnesium and 80mm for aluminum (3). In the case of the mixture $3\text{H}_2\text{O} + 2\text{Al}$, a significant portion was ejected from the charge container during combustion: this impeded determination of degree of oxidation of the metal.

In the present work investigation was conducted of combustion of mixtures of magnesium, the alloy $\text{Al:Mg} = 50:50$, aluminum with water at increased pressures and the effect of the physicochemical properties of a metal, aggregate state of water, the $\text{Me:H}_2\text{O}$ ratio, and other factors affecting degree of oxidation of metal.

Experiments were conducted in a 66 cm^3 manometric vessel incorporating means for making a tensometric recording of variation in pressure with time.

Preparation of Charge

A sample of metal (1.5 to 2g) was placed in a glass beaker (internal diameter, 20 mm) and wetted with water; quantity of water for stoichiometric mixture was computed according to the equation $\text{Me} + y\text{H}_2\text{O} = \text{Me}_y\text{O}_y + y\text{H}_2$. In certain experiments water viscosity was increased by the addition of 3 or 5% sodium salt of carboxymethylcellulose (CNC) to boiling water. This solution was mixed with metal powder; lumps were crushed with a rubber stopper. A stoichiometric mixture of 12.6% Mg and 87.4% BaO_2 was used as an igniter. Hydrogen was the only gaseous combustion product of the mixtures investigated. This permitted determination of degree of metal oxidation according to volume of released gas. Powders employed for preparation of mixtures were magnesium, Al-Mg (AM) alloy, and aluminum containing average particle size (in microns) and (in parentheses) active metal content, respectively:

35 (99.2%), 14 (96.0%), 1 (92.5%).

Combustion of Binary Mixtures of Metal Powders with Water.

The stoichiometric mixture $H_2O:Mg = 43:57$ was ignited and burned with 1 and 2 g igniter (see table 1).

Degree of oxidation in these experiments attained 65% to 71%. When water content in mixtures was increased to 50%, to 87% to 92% of magnesium was oxidized. A mixture containing 55% water yielded maximum magnesium oxidation (97%). A mixture containing 60% water did not ignite even when the amount of igniter was increased to 3 g. We also tested a mixture of magnesium with ice (50:50). To prepare this, a mixture of magnesium and water maintained one hour at -3 to -5° before the experiment was used. Combustion time for a mixture of magnesium and ice was the same as for a mixture of magnesium and water; degree of oxidation was almost identical, but the maximum pressure attained during combustion was less by a factor of almost two. The mixture of magnesium and water (50:50) gelated with 3% CMC burned somewhat more rapidly than the corresponding mixture with liquid water and yielded the maximum degree of metal oxidation attained in our experiments: 99%.

The stoichiometric mixture of alloy AM and liquid water (47:53) was not ignited by 1 to 4 g of igniter. It should be noted that failure of a mixture of metal and water to ignite was sometimes caused by formation of a layer of water on the charge surface. However, AM- H_2O mixtures could not be ignited even when this phenomenon was prevented from occurring by decreasing water content to 43% and 31%. A mixture of AM and water (50:50) gelated by 5% CMC was ignited by 3 g 4 igniter (at 2 g ignition did not occur) and burned for 10 seconds; maximum pressure was 55 atmospheres. Degree of metal oxidation in this experiment was 52%. It is interesting to note that unoxidized magnesium and aluminum in the initial AM alloy. A low-density ($\rho = 0.43$) mixture of aluminum and water (50:50) containing 3% CMC was ignited by 2 grams of igniter, and a pressure of 96 atmospheres was attained 10 seconds. Approximately 63% of the aluminum reacted with water. A charge of the same type compressed by hand ($\rho = 1.0$) was not ignited by a 2 g igniter.

Combustion of Three-Component Mixtures of Me-H₂O-KClO₄.

Upon discovering incomplete combustion of metal or even absence of ignition for mixtures of the alloy AM or aluminum with water, we decided to introduce a small quantity of sensitizer: potassium perchlorate. This salt contains 46% oxygen, does not require heat for decomposition, and is weakly soluble in water. Charge preparation included mixing solid components, sprinkling mixture in beaker, and wetting with required quantity of water. Results of experiments on combustion of binary mixtures containing an excess of magnesium and three-component mixtures containing KClO₄ are presented in table 2.

As is apparent from Table 2, the addition of combustion stimulant does not affect degree of magnesium oxidation in mixtures containing H₂O (50:50). Three-component mixtures with AM alloy containing a small amount of combustion stimulant (KClO₄, 8 to 10%) **either** did not ignite or did not burn completely (43 to 51%). Nor did the mixture containing a large amount of stimulant (16 to 18%) and 35% water burn. Ignition was observed in mixtures with water content reduced to 24%. Degree of oxidation in four parallel experiments at this concentration was 68 to 90%.

Finely dispersed aluminum could not be wet with water even when freed of fat impurities. Therefore, the beaker was divided into two parts by a vertical partition made of tracing paper. The dry mixture was located in one section and water in the other. Combustion time for such charges was considerable: 4 to 7 seconds. Degree of oxidation, however, was rather high (57 to 81%).

The experiments demonstrated that magnesium in mixtures containing water was most easily ignited and burned most completely. A small increase (in comparison with stoichiometry) in water content of a mixture (H₂O-Mg) increases degree of metal combustion. The addition of a small amount of KClO₄ to the base charge permitted realization of combustion reactions of mixtures of aluminum and AM alloy with liquid water. Apparently, reaction is facilitated by initial heating of metal particles

during combustion of a "dry mixture." Excitation of combustion in mixtures of metals and water is substantially facilitated by gelating water with 3 to 5% CMC.

CONCLUSION

Combustibility of mixtures of high-calorific metals and water is determined primarily by ease of oxidation of the metal powder.

Degree of oxidation depends on the $Me:H_2O$ ratio in the mixture.

Change in the state of aggregation of water does not effect degree of oxidation of a metal.

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Combustion of Mixtures of Magnesium and Water
(Charge Weight (Mg + H₂O) - 4.0g)

TABLE I

Physical State of Water and its Concentration in Charge, % Weight	Weight of Igniter, g	Maximum Pressures, Atmospheres	Combustion Time of Charge, Sec.	Volume of Gaseous Combustion Products, nl*	Degree of Combustion of Mg, %
Liquid, 43	1	-	-	1.37	65
Liquid 43	2	270	1.50	1.50	71
Liquid 50	1	240	1.50	1.68	92
Liquid 50	2	250	1.45	1.58	87
Liquid 55	2	220	1.75	1.60	97
Ice, 50	2	122	1.50	1.63	89
Ice, 50	2	159	1.00	1.66	91
Ice, 50	2	155	1.40	1.55	85
Liquid + Sodium Salt of Carboxymethylcellulose					
50	2	265	0.90	1.80	99
50	2	-	-	1.76	99

*nl is transliterate from the Russian translator's note.

TABLE 2
Combustion of Mixtures of Me-H₂O-KClO₄

Total Weight of Charge, g	Mixture Composition %		Results of Experiments			
	Me	H ₂ O	KClO ₄	Max. Press. Atmospheres	Combustion Time, Sec.	Gas Vol. nl*
Mixtures Containing Mg (1g igniter)						
2.6	86	0	14	16	1.5	-
4.1	55	36	9	250	0.9	1.60
4.1	55	36	9	260	1.0	1.68
4.6	49	43	8	240	1.1	1.50
4.6	49	43	8	256	1.2	1.76
4.6	49	43	8	-	-	1.59
Mixtures Containing Alloy AM (3g igniter)						
2.6	86	0	14	25	0.5	-
4.4	51	41	8	did not ignite**	-	-
3.6	62	28	10	85	1.3	0.61
3.6	62	28	10	52	1.8	0.51
3.6	62	28	10	did not ignite	-	-
3.5	64	26	10	did not ignite	-	-
5.0	49	35	16	did not ignite	-	-
4.2	58	24	18	93	1.1	0.81
4.2	58	24	18	150	1.0	1.10
4.2	58	24	18	125	1.4	1.05
4.2	58	24	18	-	-	0.99
Mixtures Containing Al *** (2g igniter)						
2.0	84	0	16	10	0.3	-
3.5	48	43	9	-	-	0.99
3.5	48	43	9	-	-	1.03
3.5	48	43	9	60	3.3	1.15
2.5	74	0	26	37	0.1	-
4.0	46	38	16	75	6.0	1.12
4.0	46	38	16	90	4.5	1.13
4.0	46	38	16	-	-	1.16
4.3	42.5	42.5	15	80	7.0	1.25
4.3	42.5	42.5	15	100	7.5	1.40
Degree of Metal Combustion, %						
2.6	86	0	14	16	1.5	-
4.1	55	36	9	250	0.9	88
4.1	55	36	9	260	1.0	92
4.6	49	43	8	240	1.1	83
4.6	49	43	8	256	1.2	96
4.6	49	43	8	-	-	87
2.6	86	0	14	25	0.5	-
4.4	51	41	8	did not ignite**	-	-
3.6	62	28	10	85	1.3	51
3.6	62	28	10	52	1.8	53
3.6	62	28	10	did not ignite	-	-
3.5	64	26	10	did not ignite	-	-
5.0	49	35	16	did not ignite	-	-
4.2	58	24	18	93	1.1	68
4.2	58	24	18	150	1.0	90
4.2	58	24	18	125	1.4	86
4.2	58	24	18	-	-	81
2.0	84	0	16	10	0.3	-
3.5	48	43	9	-	-	57
3.5	48	43	9	-	-	60
3.5	48	43	9	60	3.3	67
2.5	74	0	26	37	0.1	-
4.0	46	38	16	75	6.0	65
4.0	46	38	16	90	4.5	65
4.0	46	38	16	-	-	67
4.3	42.5	42.5	15	80	7.0	73
4.3	42.5	42.5	15	100	7.5	81

* nl is transliterate from the Russian translator's note.

** Nor did mixtures containing 32 to 37% water ignite.

*** Mixture of Al + KClO₄ and H₂O were separated by a partition.